Towards a Tailored Sensor Network for Fire Emergency Monitoring in Large Buildings

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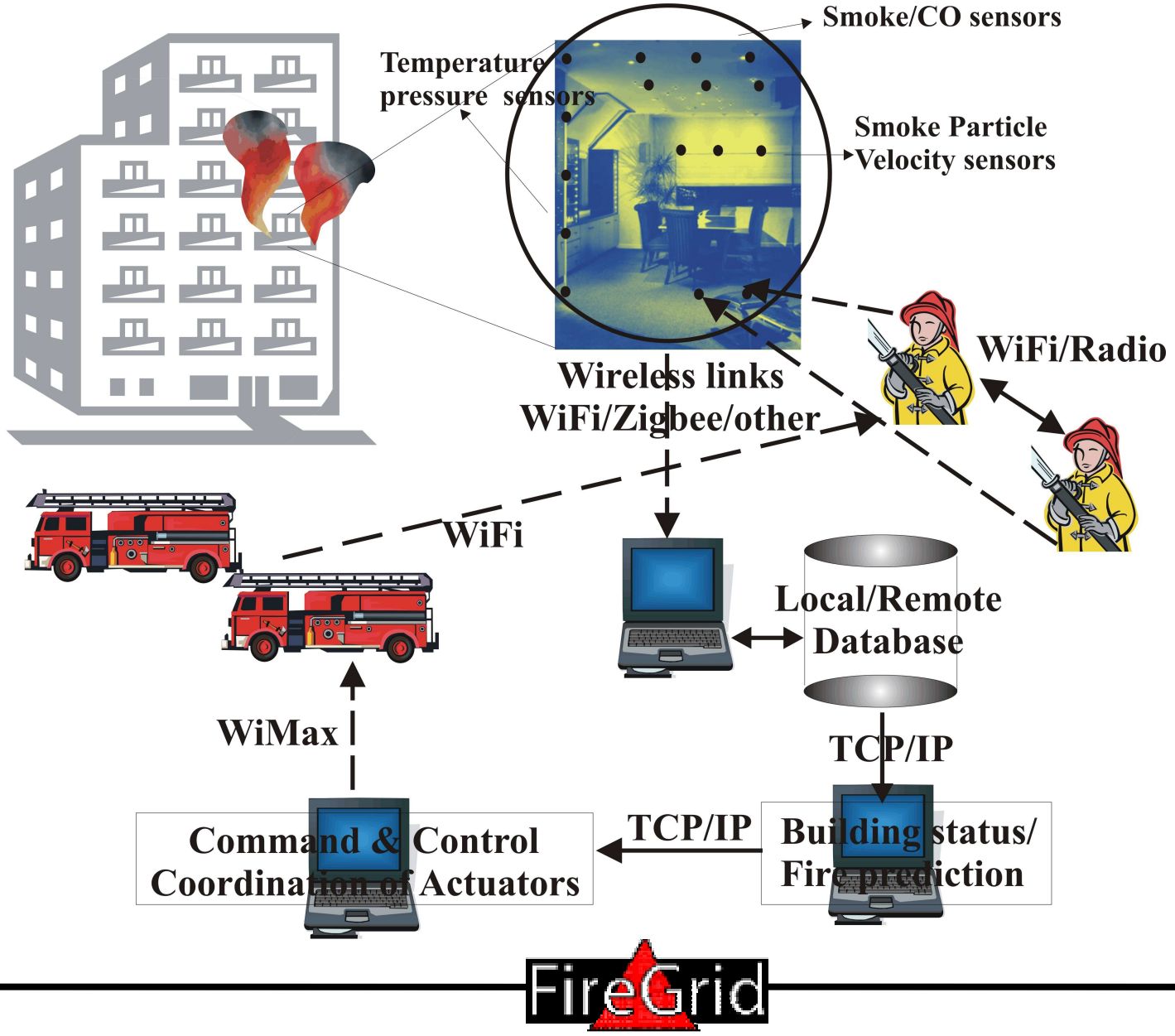
Presentation Topics

- Introduction to the FireGrid project
- Fire Scenarios and Applications
  - Smoke Movement Monitoring
  - Fire Growth Monitoring
- Initial Communication Architecture
- Clustered Architecture Based on Fire Statistics
- Key Features of a Suitable Algorithm
- Conclusions

Wireless Communications in FireGrid



FireGrid

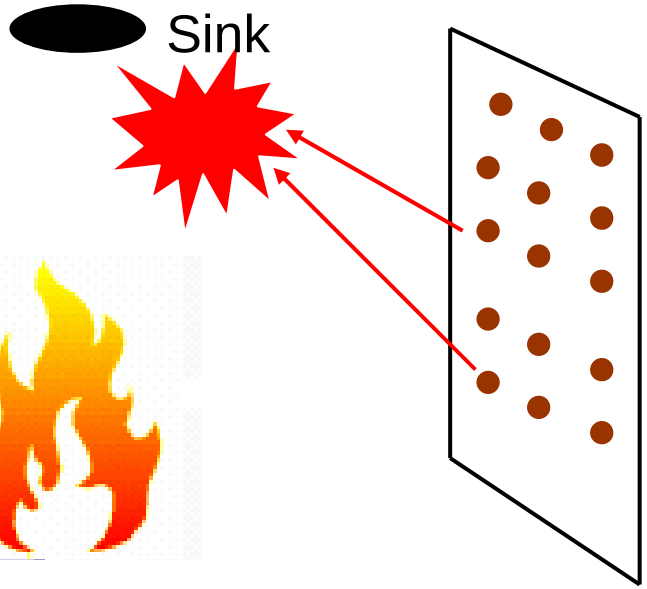
Drawbacks of a wired infrastructure

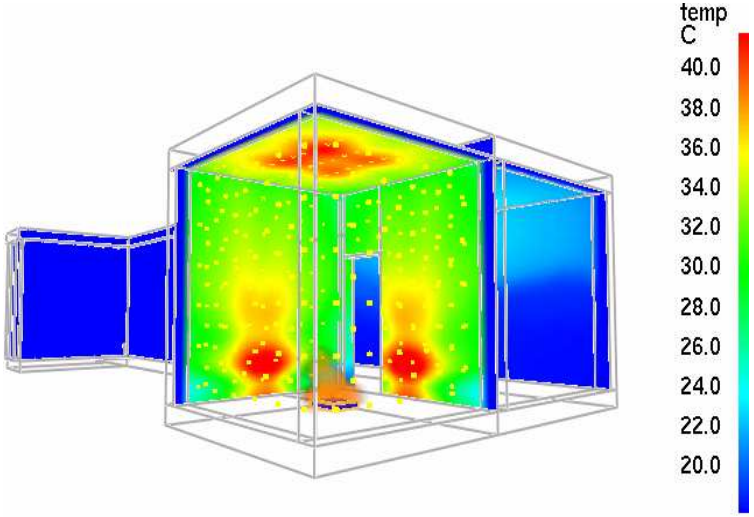
- Large buildings of the future that use FireGrid would require a network of 1000s of sensors
- For a wired infrastructure, data is transmitted reliably (no congestion or multi-path fading) but …
- Wiring is vulnerable to fire
- Wiring cost is not predicted to drop
- Wired sensors are not easily reconfigurable
- Key challenge: Extend and complement the existing wired infrastructure with **Wireless Sensors**

Why Wireless Sensor Networks?

- Enabled by the convergence of
  - micro-electro-mechanical systems technology
  - wireless communications
  - digital electronics
- Extended range of sensing
- Redundancy
- Improved accuracy
- Cost expected to go down

Research Challenges and Approach





Research Issues

- Dense sampling and frequent transmitting causes packet losses due to collisions / energy depletion
- For critical events such as a fire packet losses / latency cannot be tolerated

Approach

- Use spatial and temporal correlations in the sensed data to reduce transmission

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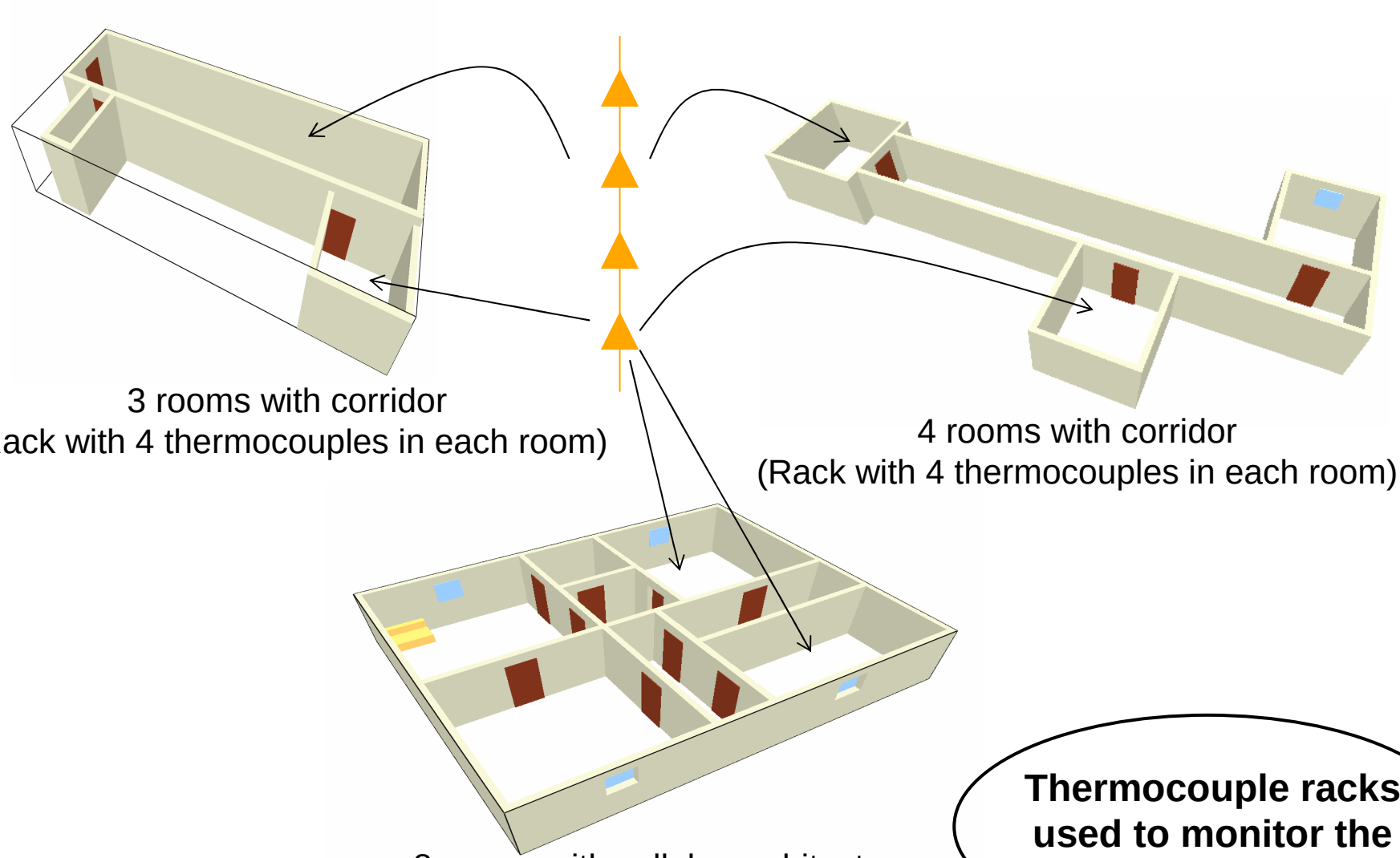
Fire Scenarios: Smoke Monitoring



3 rooms with corridor
(Rack with 4 thermocouples in each room)

4 rooms with corridor
(Rack with 4 thermocouples in each room)

8 rooms with cellular architecture
(4-thermocouple rack in each room)

Thermocouple racks used to monitor the movement of smoke

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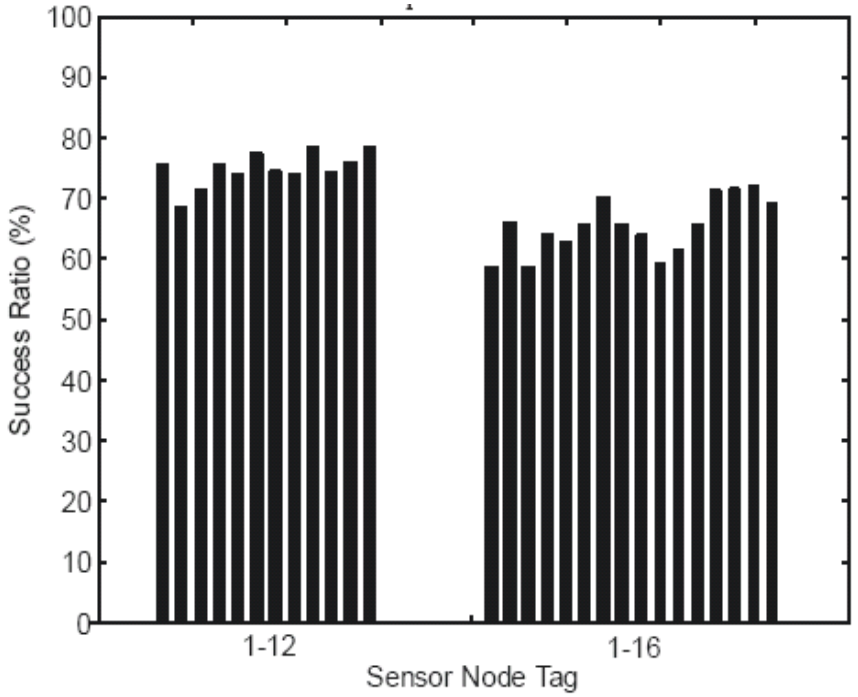
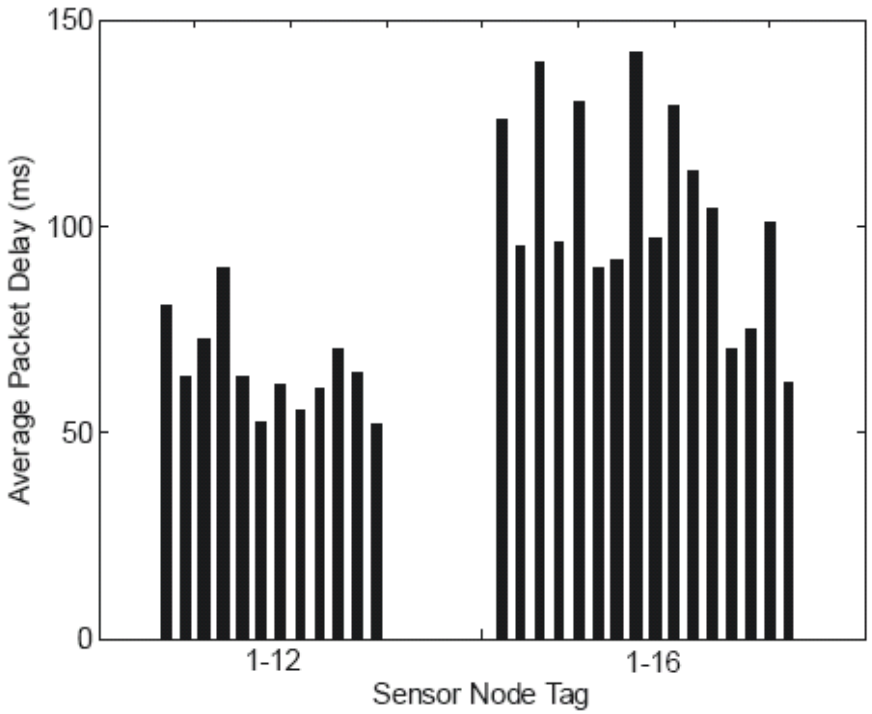
Network Simulation (NS2) Results

Percentage of packets delivered successfully



Average delay of packet delivery



- 3 room and 4 room topologies used with 4 thermocouple sensors per room
- Single Hop, Flat architecture with all sensors speaking to a sink
- Constant transmission rate of 1 packet per second
- Significant packet losses due to collisions

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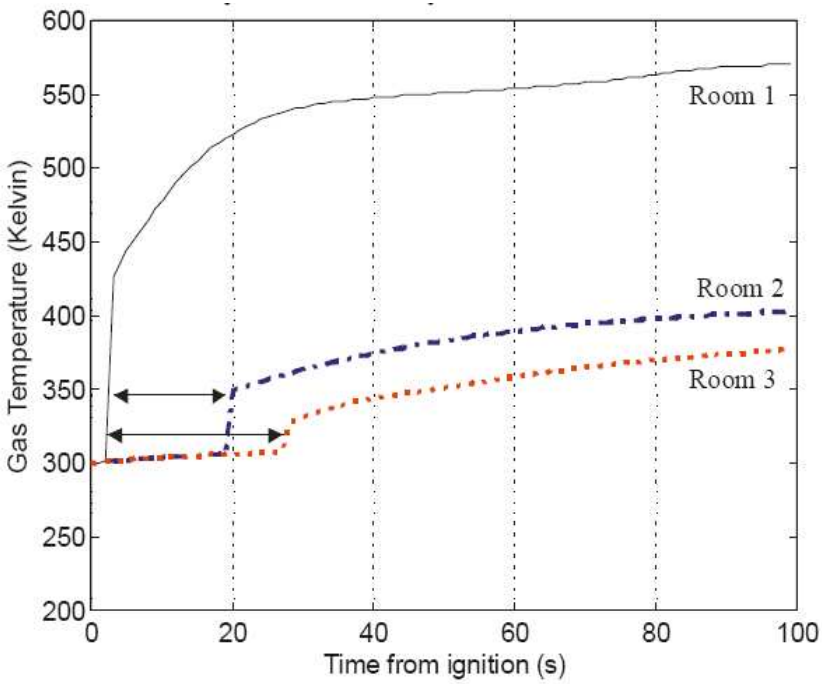
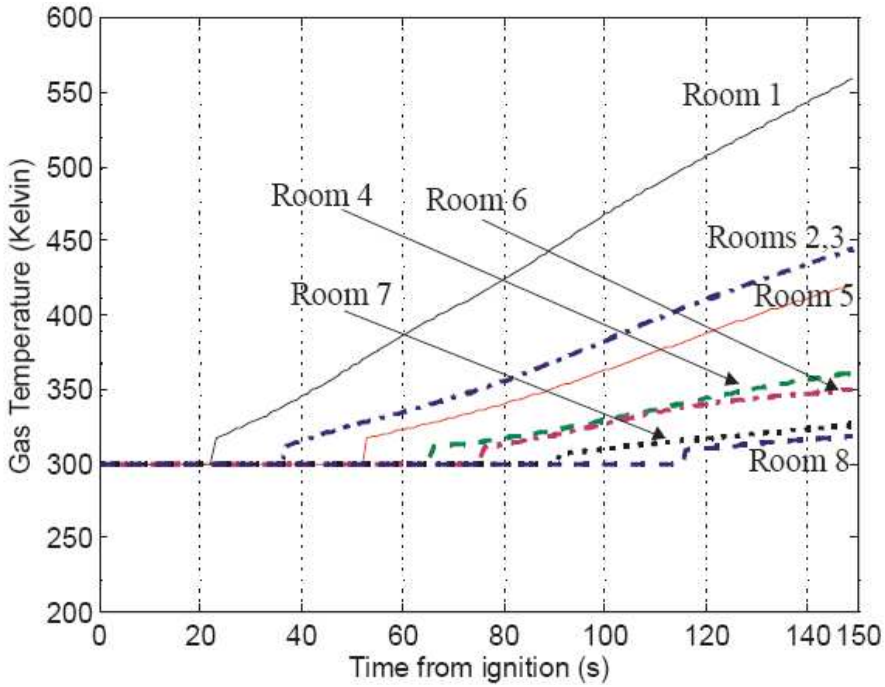
Fire Data Characteristics

Temperature reading of topmost thermocouples of each room in 3 room scenario



Same for 8 room scenario



- Similar temperature profiles in each room but lagged in time
- Sensors in other rooms need not transmit for certain time intervals
- Time sliding effect can be exploited to reduce transmissions

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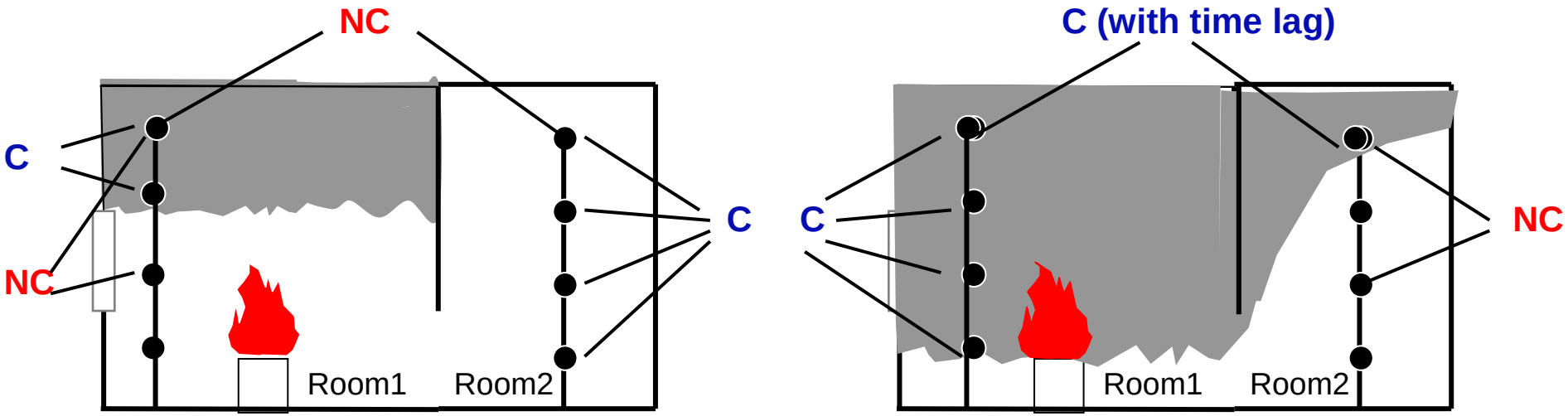
Correlation Structure in Multiple Room Fires

Example: Dynamic Correlation Structure



Time t_1 Later time t_2

C : Correlated

NC: NOT Correlated

- Sensors that are correlated can be clustered together
- Correlations among sensors change with time
- Similar phenomena at different rooms but with a time lag

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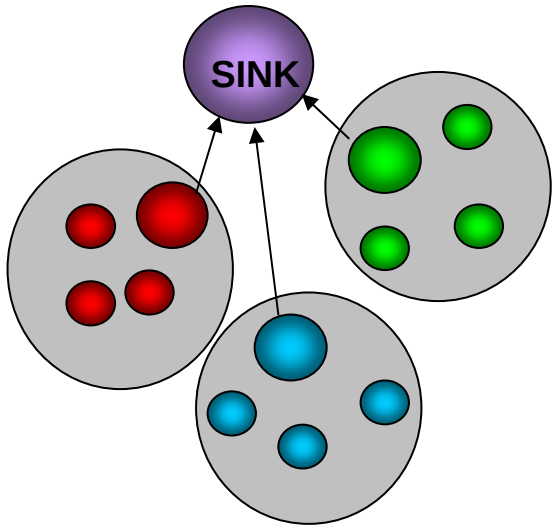
Clustered Network Architecture

Partition of sensor network into clusters



Comparison of power consumption of IEEE 802.11 for flat and clustered network

IEEE 802.11		Power Consumption for 2000s (in Joules)	Network Lifetime (in days)
Flat	3-room	1854	0.38
	4-room	1854	0.38
	8-room	1854	0.38
Clustered α=1/4	3-room	467	1.53
	4-room	467	1.53
	8-room	467	1.53

- How to group the sensors into clusters?
- What is the error in sensor field representation at the sink?
- **NEED TO EXPLOIT CORRELATIONS IN THE FIRE DATA FOR CLUSTERING !**

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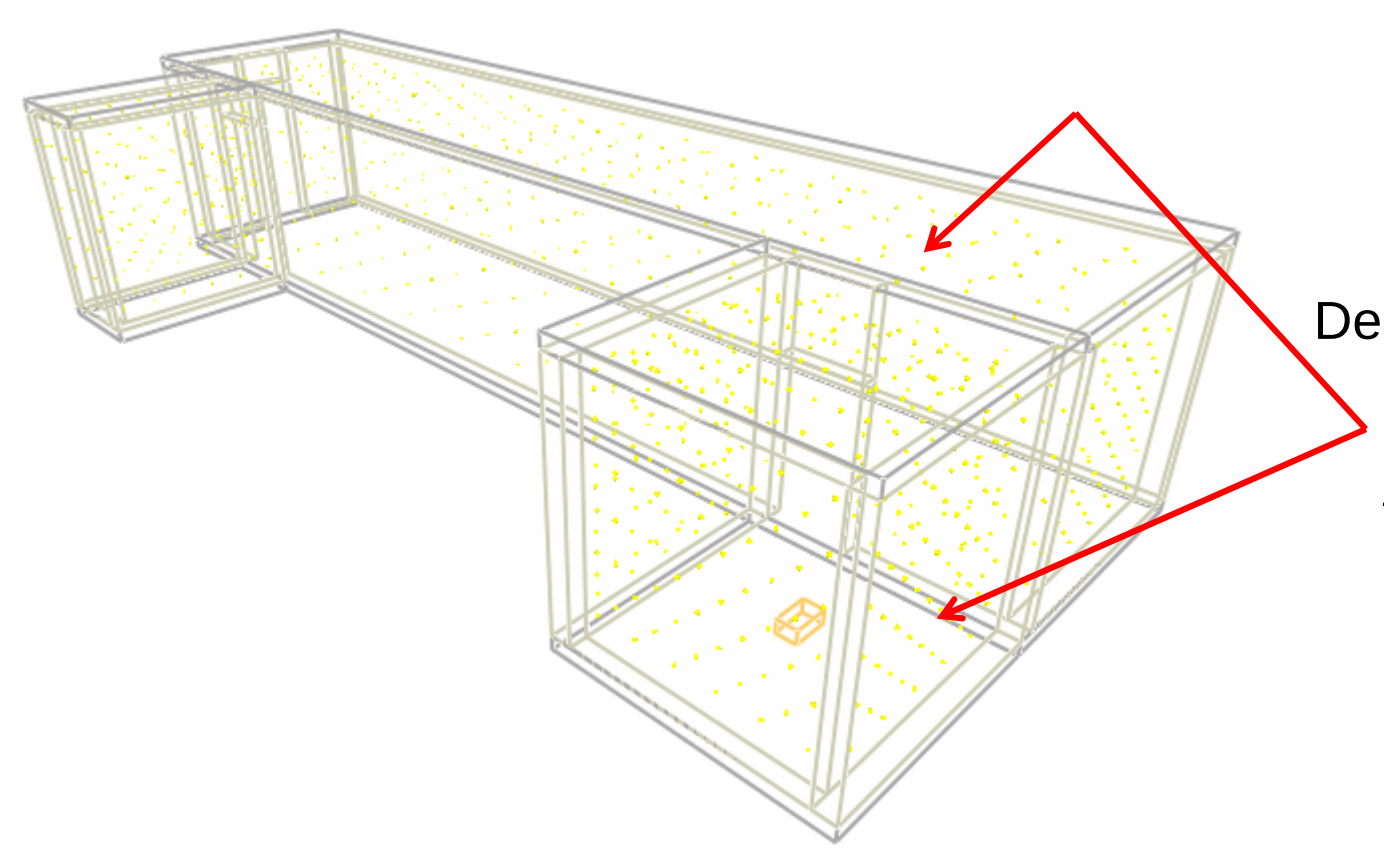
Fire Growth and Spread Monitoring



Dense Wireless Network
of ~ 300
thermocouples
to measure the wall
temperatures

- Dense coverage by wireless sensors provides very early detection, precise localisation of fire and continuous monitoring of growth.

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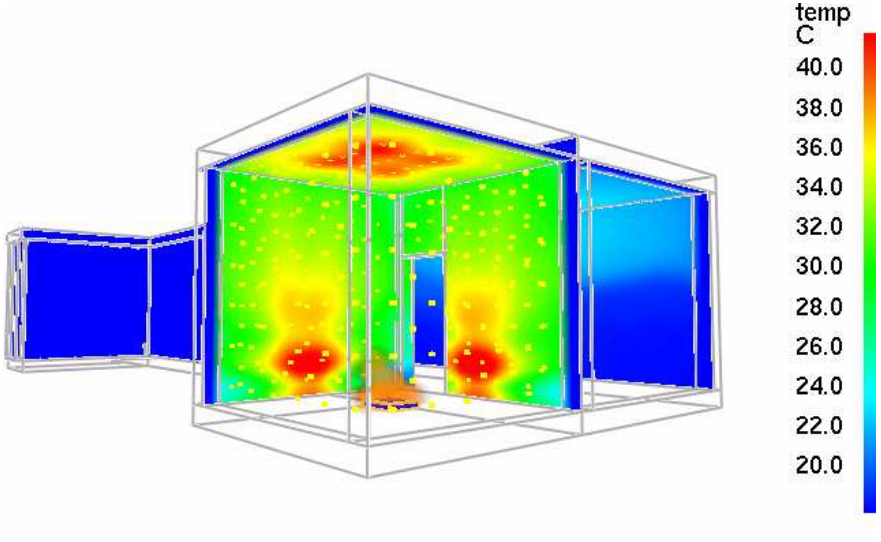
NS-2 Simulation Results

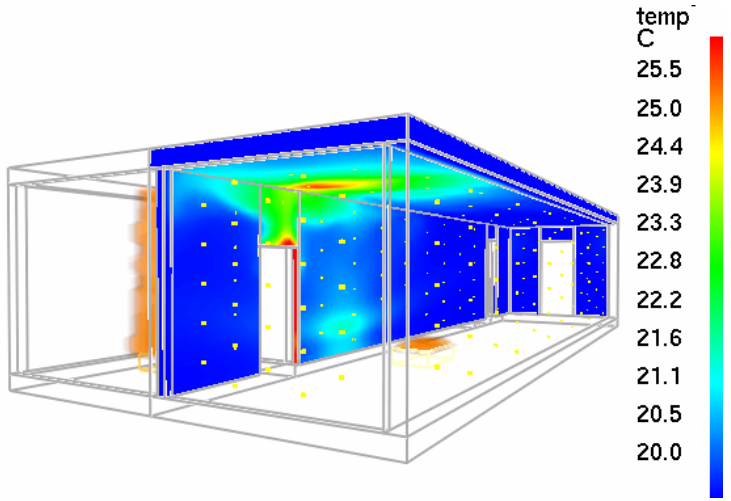
Protocol	Packet Loss %	Transmission Delay (ms)	Power Depletion (J)	Lifetime (hrs)
802.15.14	39 +/- 8	23 +/- 2	213	144.6
802.11	0 +/- 0	1 +/- 0.1	4230	7.3

- Direct one-hop uplink traffic from every sensor to the sink.
- Packet size 11 octets, constant rate of transmission of 1 sample/second.
- WiFi (802.11) has LOW Packet Loss but SHORT Lifetime.
- Zigbee (802.15.4) has HIGH Packet Loss but LONGER Lifetime.

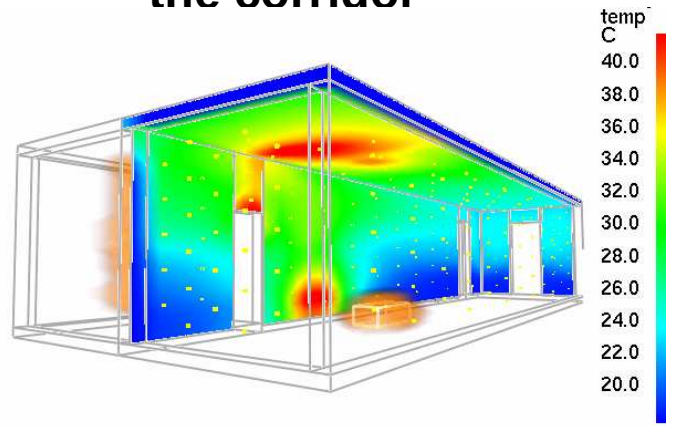
Various stages of fire growth and spread



Stage 1: Ignition and Growth of Fire in the Main Room



Stage 2: Secondary Fire ignites in the corridor



Stage 3: Secondary Fire grows

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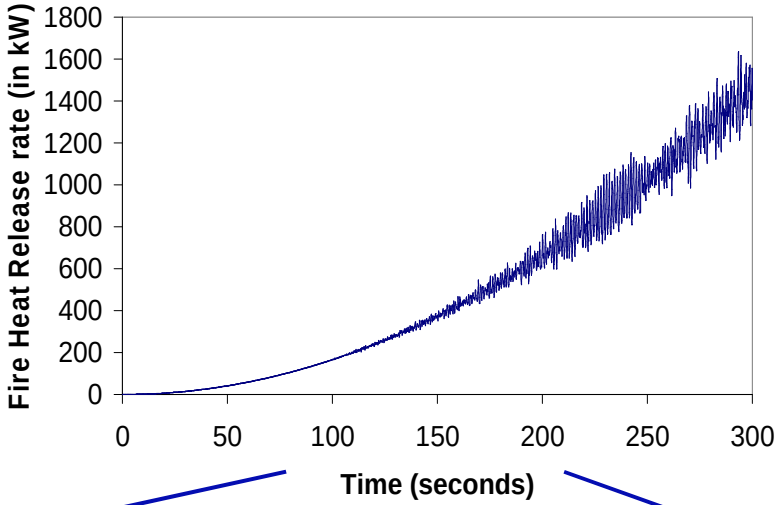
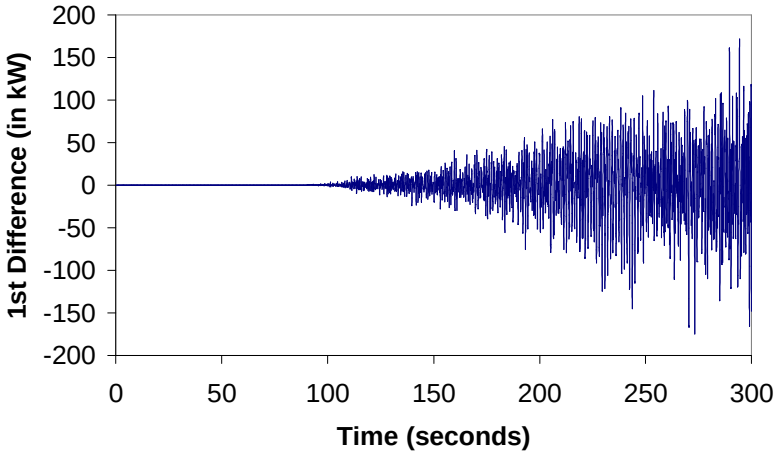
Difficulties in signal processing

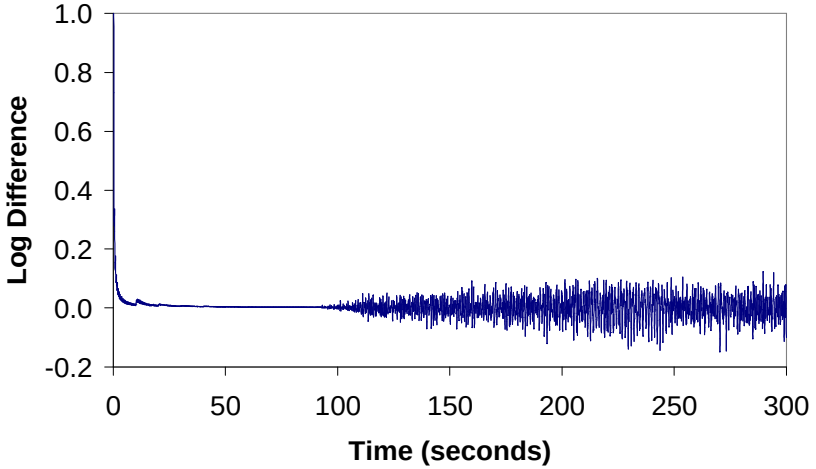
Highly non-stationary signal to be measured:



Differencing



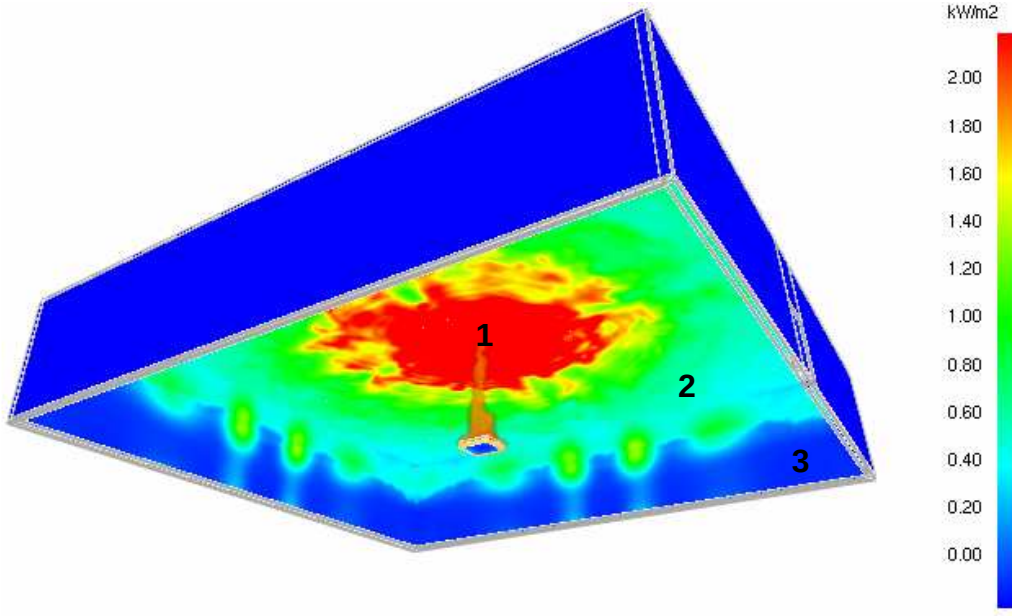
Log-Differencing



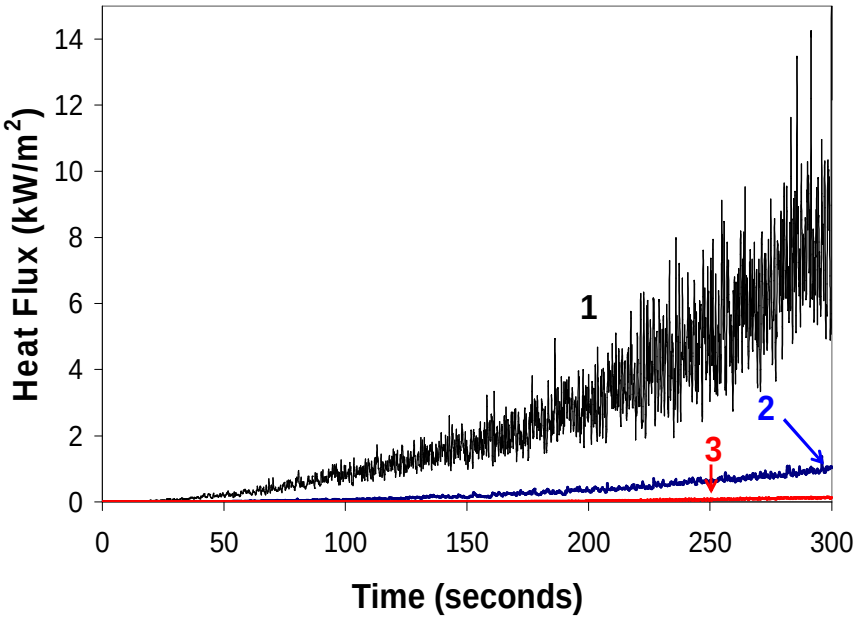
Neither differencing nor log-differencing result in stationarity!

Example of Signals measured by Wall Sensors

Heat Flux profile at walls and ceiling



Heat Flux signal at selected points



- Heat Flux / Temperature directly above the fire peaks first and a front propagates along the walls.
- Spatio-Temporal Correlations of advancing front can be leveraged in the communications protocol.

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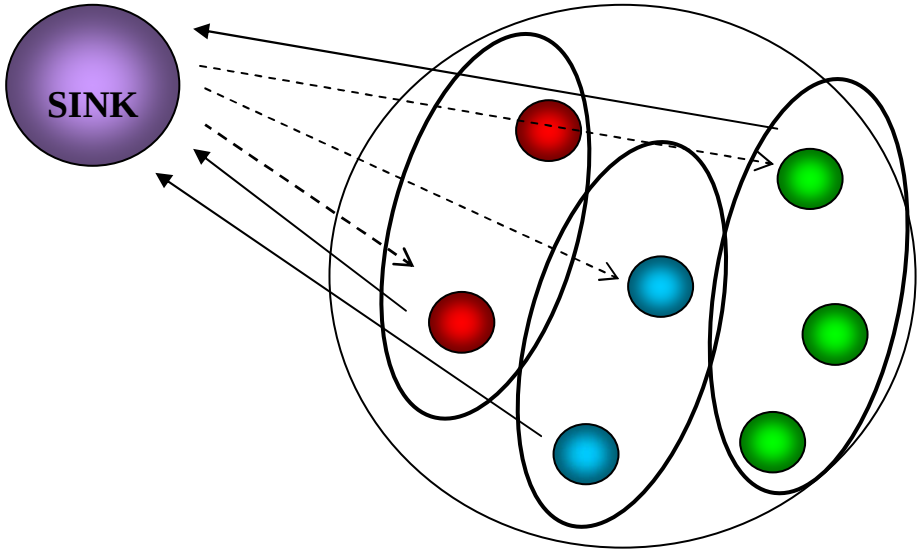
Features of a Suitable Algorithm



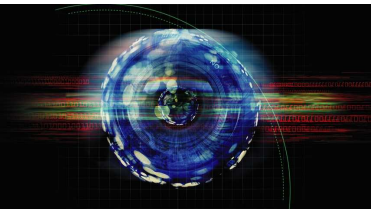
Suppose a Centralized Medium Access Control Scheme is used in a single hop network with star topology…

- Sink should dynamically select a subset of sensor nodes based on a minimum distortion criterion
- Correlations change with time and the number and optimal selection of sensors depend on them
- Sink should be able to determine when the correlations change and assign appropriate nodes to transmit

Conclusions

- FireGrid concept requires a highly dense network of sensors and wireless seems to be an attractive option
- Dense sampling + high transmission rates cause degradation of performance of widely used communication protocols
- Correlations in the fire data can be used to reduce transmissions
- Clustering is a method of exploiting these correlations
- Key features of a suitable algorithm were discussed

Technology Strategy Board



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